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Shear Stress Analyses in Chemical Mechanical Planarization Processing with Cu/porous low-k Structure

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1. Introduction

Recently, porous low-k materials are required for the construction of LSI devices.[1)] However, the extremely low Young's modulus values of these materials result in a significant number of defects.[2,3)] Reported solutions for these problems are as follows; lower downward pressure[4,5)], lower friction[8)], and control of real contact area between the surface of a device and the pad/abrasives[5,8)] in chemical mechanical planarization (CMP). The authors reported the horizontal stress field at the surface of Cu/porous low-k structures assessed by finite element method (FEM) during CMP and that stress concentration induced defects such as stress corrosion cracking (SCC).[5-7)] However, other stress fields, especially shear stress distribution, is not well understood although shear stress may induce delamination of low-k films during CMP.[4)] In this study, we demonstrate the relation between the stress field in depth during CMP and the ILD structure.

2. Experiments

The schematic of FEM is summarized in Fig.1. A uniform downward pressure of 13.8 kPa (2 psi) and a horizontal frictional force of 4.8 kPa (0.70 psi), 4.8 kPa (0.70 psi), or 5.9 kPa (0.86 psi) [6-9)] were assumed to be applied to the surface of Cu, low-k, or Ta film, respectively. For the estimation of the effects of Young's modulus of the stacked ILD structure, several kinds of hard mask (HM) and bottom low-k film having different Young's modulus were applied (Table 1). It is also noted that the real contact area between the surface and the CMP pad is quite limited, typically 0.4 %[5,10)] of the whole surface. Moreover, considering the agglomeration of abrasives, the real contact area should be much lower. Therefore, we hypothesized that the real contact area, considering both a pad and abrasives would be *0.1 %* and that the real stress field was provided by the division of the FEM results by *0.1 %*. The datasets of the following figures are the values after the division.

3. Results and Discussions

Figure 2 represents the Von Mises stress around an isolated line with four kinds of a stacked structure. It was found that higher stress was appeared in a structure with lower modulus. The maximum tensile stress appeared at both edges of the wiring surface, showing a good correspondence with the reported results.[6-8)] Moreover, outstanding stress concentration appeared along the sidewall of the trench. Figure 3 shows the vertical stress profiles along the left ((a), (c)) or the right ((b), (d)) trench wall, where the ILD structures were the same as Fig.2. It was revealed that the high shear stress area was found around the ILD boundary with the large modulus difference as well as the lower Young's modulus (Figs.3 (a), (b)). This suggests that the porous low-k film just below the HM having a higher modulus is more suffered from the shear stress and has much possibility of the delamination. Moreover, Fig. 4 indicated that the shear stress increased after the removal of the barrier. That is to say, shear stress should have the maximum value after the barrier CMP, especially with the lower modulus structure. This result showed a good correspondence with the reported phenomenon that delamination of low-k films happened during the barrier CMP.[4)] On the other hand, it was revealed from the results in Figs.3(c) and (d) that the horizontal stress was always compressive except for the surface.

The same FEM analyses were also performed with dense Cu lines and summarized in Fig. 5. A shear stress at an isolated line was always higher than that of the dense lines, which suggested that dummy patterns could decrease the shear stress. From the effect of frictional force shown in Fig. 6, it was confirmed that frictional force increased the shear stress. This indicated that a slurry with lower frictional force should be effective to minimize the shear stress and to avoid delamination.

4. Conclusions

We demonstrated that the FEM results could predicted *"dangerous"* stress fields during CMP. It was revealed that shear stress was concentrated on the ILD boundary with a large modulus difference. This suggested that more attention should be paid to the modulus difference of ILD films in order to prevent defects such as delamination. Moreover, stresses at dense lines always showed lower values than that at isolated lines. Thus, it is expected that a dummy layout is effective to minimize defects induced by CMP. Furthermore, it was confirmed that shear stress was sensitive to frictional force. Hence, not only decreasing downward pressure but also minimizing frictional force is a clue for successful CMP with porous low-k structure. Recently, a low friction slurry has been reported[5)] with successful electric characteristics. It should be again noted that these results were based on the assumption that actual contact area is 0.1%. Thus, an inadequate pad and/or slurry condition leads to much lower real contact area inducing much more defects. Therefore, a well controlled contact between the LSI surface and the pad / abrasives is also quite important. Consequently, these conclusions provide a useful suggestion for future work of Cu/porous low-k CMP processing of LSI devices.

References

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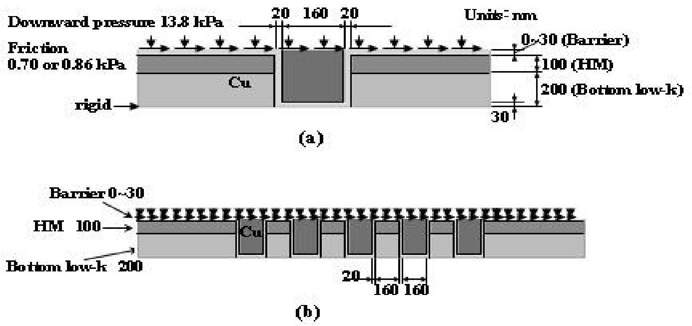

Fig.1 Schematic of FEM analyses

Film		Youngs modulus (GPa)	Poisson's ration
Wiring	Cu	129.8	0.34
Barrier	Ta	185.7	0.34
HM	TEOS	60	0.27
	Dense MSQ	20	0.25
	SiOC	11	0.25
Bottom low-k	Porous MSQ(a)	5	0.25
	Porous MSQ(b)	2.5	0.25

Table 1 Numerical conditions

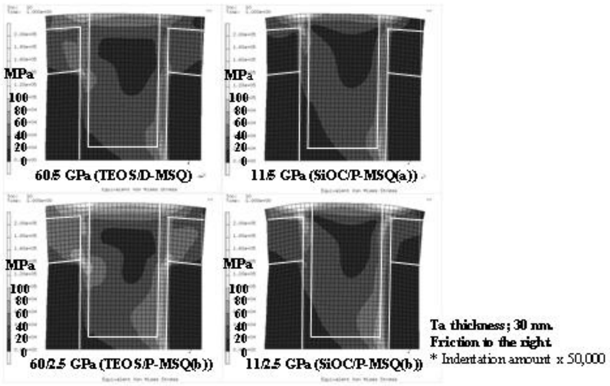

Fig.2 Von Mises stress distributions

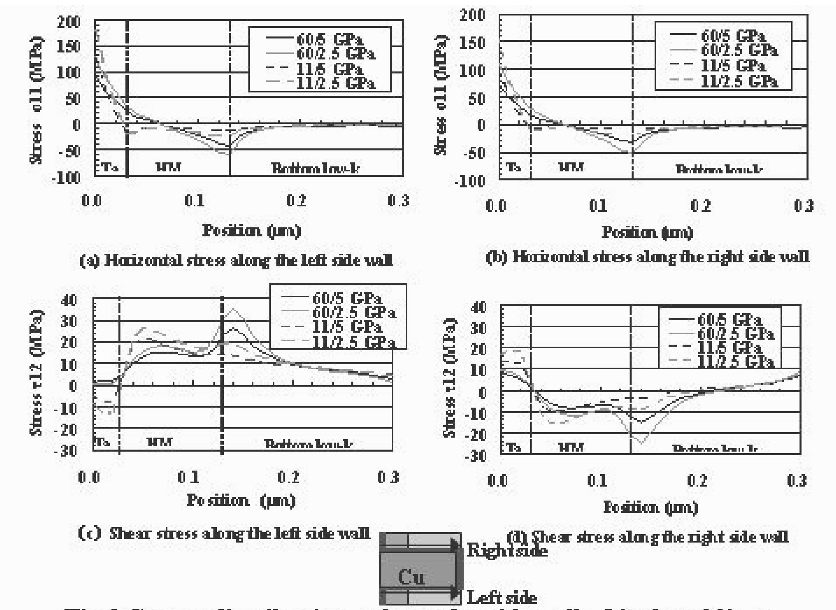

Fig.3 Stress distributions along the sidewall of isolated line

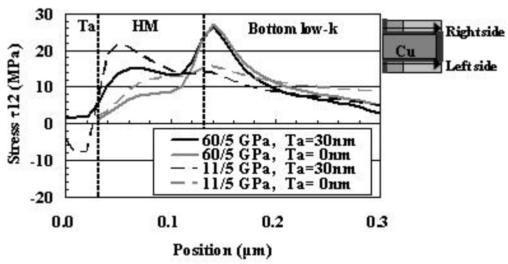

Fig.4 Shear stress along the left side wall of isolated line

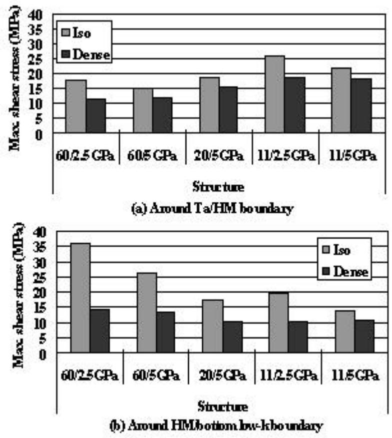

Fig.5 Maximum shear stress around the ILD boundaries

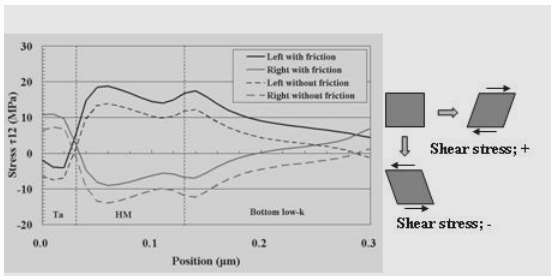

Fig.6 Effect of friction on shear stress at isolated line with 20/5 GPa stacked structure